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Impact of Elevated CO_2 on Growth and Yield of Wheat Crop: A Review

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Abstract

In this manuscript, 19 research studies with 79 experiments from 9 countries of the world based on growth, yield and their components of Wheat (*Tritium aestivum* L.), under various CO_2 levels was analyzed. Only the recently published research studies (excluding models and mathematical tools based research) were considered in the study. Most of the selected experiment confirmed that elevated CO_2 have positive impact on growth, yield and its components. Majority of the observations confirm that the elevated CO_2 improved the growth & development processes as well as the yield & yield attributes of Wheat crop. No doubt elevated CO_2 have positive impact on various growth and yield parameters but when we consider the impact of climate change (elevated temperature, drought, and increasing concentration of anthropogenic gases like SO_2, CO, CH_4 etc.) the response of CO_2 will become negative. Even though elevated levels of CO_2 has potential to compensate the impact of other changes in climate and may create a path in future to meet the demand of burgeoning world population.

Highlights

- Total 19 field studies with 79 experiments from 9 countries of the world based on growth, yield and their components of Wheat (*Tritium aestivum* L.), under elevated CO_2 levels were used for analysis.
- Elevated CO_2 shows positive response on growth and yield of wheat crop.
- When other factors like elevated temperature, drought, and other pollutant gases like Ozone or SO_2 combines with elevated CO_2 the response will become lesser or some time negative.

Keywords: Elevated CO_2, Wheat, Photosynthesis, Growth, Yield, Meta analysis.

Wheat (*Triticum aestivum* L.) is one of the most important and widely cultivated crops in the world, and provides 20% of food calorie and 22% the daily protein for 4.5 billion people. Estimated Global population was 6.08 billion for the year 2000-01 and anticipated to be around 9.6 billion by the end of 2050 (UN, 2013). According to this report India would cross the population level of China and expected to be the world's most populated country in 2028. Such a linear increase posed a serious challenge to meet the future food requirements. FAO has projected to increase in food consumption up to 70 percent to meet the requirement of ever-growing world population. For the fulfillment of the demand it is expected to increase in total crop production about 45 percent from current production i.e. 7.68 billion tons (Alexandratos and Bruinsma, 2012). Expected world's average calorie intake in year 2050 would be 3130 kcal per person which is about 11 percent more as compare to year 2003 (FAO,2006). Projected world's arable land availability per capita would decreased drastically from 1960 (0.45 mha) 2050 (0.19 mha). The problem will be more serious in developing country (0.14 mha) as compare to developed one (0.43 mha) in comparison to year 1960 i.e. 0.33 and 0.70 mha respectively (FAO, 2009). Arable land and agronomic evidence in production of crop is near to saturation very little chance of increment (Fig.1 a and b). Agronomic advances is one of the option to sustain the productivity of crops (Dubey *et al.*, 2014)

Climate change will be one of the prime concerns for humanity in the 21st century. Growing evidence regarding observed changes in the climate system had proven its reality. The Intergovernmental panel on Climate change fifth assessment report concluded that it is majorly attributed to human-induced activities. Study based on geological and paleo-climatic facts shows that present atmospheric CO_2 concentrations are higher than at any time in the last 15 million years (Tripati *et al.,* 2009). Major Green house gas CO_2 has reached up to 397 parts per million (ppm) in January, 2014 (http://co2now.org/) from its preindustrial concentration of 278 ppm and continue to rise at 1.8 ppm per year (Blunden and Arndt, 2013). Recent study on the CO_2 concentration in atmosphere shows that ~350 gigatone of carbon (GtC) equivalent to 1285 billion metric tons of CO_2 have been emitted through human activities since 1959 (Ballantyne *et al.,* 2012). In absence of further policy, if the current trend is continue global CO_2 concentration will reach 41 billion metric tons of CO_2 per year in 2020. In spite of the huge research efforts to meet the calorie demand of ever growing population, there are still large gaps between the estimates of yield from lab to land (IFPRI, 2002). It may create a serious problem to mitigate the future food security in context of the changing climate.

Regardless of these striking forecast in increasing global warming and abrupt warmth events, IPCC assessment report has predicted that adaptation of agriculture will result in surplus in production of major cereals like wheat and rice. The negative impact of temperature is compensated with high level of CO_2 resulting increase in production. Plants are directly affected by increasing level of CO_2 concentration because it is the first molecular link from atmosphere to biosphere. It serves as substrate to photosynthetic carbon assimilation. There is concomitant decline in photorespiration process and alteration in stomatal activity (Idso, 1995). C_3 plants like Wheat, Rice, Oilseeds and pulses respond to elevated CO_2 since it reduce the oxygenase activity of Ribulose-1, 5-bisphosphate corboxilase oxygenase enzyme (RuBisCO) in plants. RuBisCO involved in the first major step of carbon fixation, a process by which atmospheric carbon dioxide is converted by plants to energy-rich molecules such as glucose. Long *et al.,*(2006) have attributed the elevated CO_2 induced photosynthesis to- (i) competitive inhibition of the oxygenase activity of RuBisCO, and (ii) acceleration of carboxylation because the CO_2 binding site is not saturated at the current CO_2. C4 plants like Sorghum, Maize and Sugarcane shows little or no photosynthetic response to elevated CO_2 because C_4 pathway is not competitively inhibited by O_2 and is completely CO_2 saturated.

It has been proved with number of research experiment conducted worldwide that elevated CO_2 increases the rate of photosynthesis and decreases photorespiration in C_3 plants like Wheat (Sage *et al.,*1989; Bowes, 1991 and Kimball,1983). RuBisCO is bi-functional enzyme capable of carboxylation as well as oxygenation of Ribulose-1, 5-bisphosphate and responsible for the reaction of CO_2 with RuBP during photosynthesis. The reaction is not saturated properly at ambient CO_2 levels also Oxygen (O_2) react with RuBP, Producing phosphoglycolate which is metabolized ultimately releasing CO_2 in photorespiration. Elevated CO_2 saturates RuBisCO and greatly decrease photorespiration, resulting increase in photosynthesis by 30-40% (Long, 1991). Although elevated CO_2 decreases the stomatal conductance with potentially large reductions in water loss, the increased atmospheric CO_2 is more than sufficient to compensate it, so that the internal CO_2 concentration is greatly increased. Wheat exhibits these typical responses (Uprety and Reddy, 2008). Over all elevated CO_2 increases the carboxylation of RuBisCO, and leaf water status by stomatal conductance which increases leaf expansion ultimately accumulates more and more photosynthesis, same time elevated CO_2 reduced the photo respiration resulting increased production (Fig. 2).

The crucial effects of rising CO_2 on wheat plants have been well documented and include as reduction in stomatal conductance and transpiration, therefore improved water-use efficiency, higher rates of photosynthesis, and increased light-use efficiency resulted (Drake *et al.,* 1997, Wenlong *et al.,* 2007). The majority of these conclusions from studies of individual species grown in controlled environments or enclosures (Wolf and Diepen 1995, Ludwig *et al.,*2009). Number of reviews has been conducted to observe the real impact of elevated CO_2 on wheat all across the world (Kimball, 1983; Cure, 1985; Lawlor and Mitchell, 1991; Amthor, 2001). Kimball, (1983) has reported the response (yield) of 37 species grown under elevated CO_2 by using 430 set of observations, Cure, (1985) has presented a basic idea about impact of elevated CO_2 on physiological aspects of crop, and Lawlor and Mitchell (1991) have compared the result of lab and field experiment on yield of Wheat crop. Amthor (2001) has critically reviewed the effect of elevated CO_2 on wheat crop using 50 studies, but the study have major focus on yield and yield components of wheat crop using various CO_2 control technology i.e. green house, lab chamber, open top chamber, closed top chamber, and FACE. There is number of research experiment have been conducted to evaluate the growth and its component of wheat under elevated CO_2 but the overall response around the world is not published yet.

Because of number of person dependency on wheat it is very crucial to determine the physiological, phenological and nutritional status of wheat under changing climate situation. Keeping the facts in mind a meta analysis of research studies from different part of world carried out using various technological approaches related with elevated CO_2 are selected to review the extent of actual impact, whether it is positive or negative. Also study reveals the technological evidence, research gap and future scope of work in the area of climate change mitigation and adaptation. To simplify the work study has been divided in three broader groups – a) Impact of elevated CO_2 and growth and growth parameters, b) impact of elevated CO_2 and yield and yield parameters.

Historical development of co_2 fertilization research

Research on CO_2 and its role in photosynthesis as well as growth and development of plant is not new concept it has started with the study of Stephane hales in year 1727 reported green part may get their part of nourishment through their leaves and sunlight may have to do something with it. In third quarter of 17^{th} century Priestley has proposed the idea of gas exchange during the photosynthesis. Ingenhauz in 1979 an Austrian botanist plants purify the air only in presence of light. Only the green part of plant produces purifying agent (O_2) while non green part produces pollutant (CO_2). Jean Senebier in 1800 recognized the O_2 liberated from the plant during photosynthesis comes directly from CO_2 which was absorbed by plant. Liebig in year 1840 first time reported the sole source of carbon (an essential element) in plant was obtained from CO_2. De Sassure in 1804 has noted the faster growth in Pea plant with an elevated atmospheric CO_2 (8% CO_2). John tyndal was first to report the CO_2 green house effect. About 4000 acres of greenhouse crops were being grown with CO_2 enrichment. Sachs in 1887 reported that green chloroplast, were the organ where CO_2 was used up and O_2 was liberated. And starch was the first visible product of photosynthesis. Moll's half leaf experiment showed that CO_2 was necessary for photosynthesis (Uprety and Reddy, 2008). From the available records it seems to be lab experiment on "CO_2 fertilization" and its impact on plant growth and development started around the early 19^{th} Century. Lundegardh is first scientist in the world who carried out CO_2 enrichment experiment on field crops (Sugar beet and Oat) in year 1920-23. He has recorded 16% increase in sugar beet root production by 15% increase in CO_2 where as Oat production was 30% more by doubling of CO_2 from 282 to 564 ppm (Wittwer, 1986).

Methodology

Criteria used for meta analysis

A comprehensive literature survey have been performed using peer reviewed research articles related to impact of elevated CO_2 on growth and yield components of wheat. To search the relevant literature the major keywords used are- growth/plant height/leaf area/ number of tiller per plant/ number of leaf per plant/ leaf length/ leaf width/ leaf duration/ yield/number of ear per plant/number of grain per ear/grain weight/TGW/harvest index (HI)+ elevated CO_2+Wheat/*Triticum aestivum*+ experiment.

Total 721 articles shown on the ISI web of science webpage (Thomson Reuters) which consists of number of modeled studies or studies conducted before 2000 or something irrelevant with our area of interest. Only 19 studies with 79 experiments were found relevant with our topic and have been used in Meta analysis. The selected articles need to fulfill the criteria given below:

1. It has to be studied at least one variable either on growth or yield (plant height, leaf area, number of tiller per plant, number of leaf per plant, leaf length, leaf width, leaf duration, yield, number of ear per plant, number of grain per spike, grain weight, TGW and harvest of wheat crop.
2. The articles must be related with elevated CO_2 experiments.
3. The study must be based on comparison between control and elevated CO_2.
4. Modeling studies not considered for Meta analysis.

Percent change detection

Analysis of CO_2 impact mentioned in the study is the percent change of particular parameter from control (ambient) to elevated CO_2 and other particulars. The formula used is

$$C_{\%} = \frac{E - A}{A} \times 100$$

Where, $C_{\%}$ = Percent change, E= Result obtained with elevated CO_2, A= Result obtain at control or ambient CO_2.

Results and Discussion

Effect of elevated CO_2 on growth and growth components

Total 16 peer- reviewed already publish studies including 31 experiments focusing on elevated CO_2 on growth component (as a part or whole study) of Wheat crop has been taken in consideration (Table 1). The concentration of CO_2 ranges from 300-900 ppm with most between 350-750 ppm. Only one study included which have CO_2 concentration up to 900 ppm (Masle, *et al.,* 2000). In this study main growth component e.g. No. of Tiller/ plant, Plant height (cm), Leaf Area Index, Above ground biomass (dry weight g/m2) it includes Leaf, Stem, Root, Ear head and total plant biomass of wheat crop. Component wise response of elevated CO_2 is given below.

Response of CO_2 on number of tiller per plant at 40 and 60 DAS was reported by Deepak & Agrawal, (1999) he has observed that 19.7 and 14.7% change from ambient CO_2. SO_2 is having negative impact on both time periods but when it combines with CO_2 the response is increased significantly as compare to response of CO_2 alone.

Six studies, including 21 experiments were analyzed to see the response of elevated CO_2 on plant height of different wheat cultivar in various part of the world. Most of the studies were performed under open top chamber (OTC), only one experiment carried out under closed top chamber (CTC) or green house (Wu, *et al.,* 2004). The percent change over control varies from 1.98 (in addition to 200 kg Nitrogen in OTC) to 56 percent (in addition to 80% FWC-field water capacity). Total eight studies with 46 experimental findings were analyzed to see the impact of elevated CO_2 on leaf area index (LAI) of wheat crop. The effect varies from 2.6 - 82.2 percent. Effort being made to observe the LAI at different growth stages of crop i.e. Jointing (J), Flowering (F), and Grain filling (GF) under varying management level (Li *et al.,* 2007). Impact of CO_2 concentrations on above ground biomass (dry weight g/m^2) of different varieties of wheat crop under varying climatic situation were reviewed critically. Above ground biomass study was divided in 5 sub sectors viz., impact of CO_2 leaf biomass, stem biomass, root biomass, ear biomass and whole plant biomass. To review the leaf biomass (dry weight g/m^2) 10 studies with 27 experiments were analyzed. The impact varies from -14.7 (Pal, *et al.,* 2005) to 49.31 (Deepak and Agrawal, 1999) percent change over control. Seven peer reviewed studies with 21 experiments were analyzed to see the impact of stem dry weight as affected by various elevated CO_2 levels. The impact varies from – 9.75 (Deepak & Agrawal, 1999) to 143.9 (Pal, *et al.,* 2005)% change over normal or ambient CO_2. In comprehensive search result only two studies (Pal, *et al.*, 2005 and Gonzalez *et al.*, 2013) with eight experimental findings related with root

Table 1. Impact of elevated CO_2 on growth and growth parameters of Wheat crop

S. No.		CO_2 level (ppm)	Interactive factors	Percent Change ($C_{\%}$) in Growth Parameters								Study area	Species/ Variety	Tech. used	Source
				No. of Tiller/ plant	Plant height	Leaf Area	Above ground biomass (Dry weight g/m²)								
							Leaf	Stem	Root	Ear	Plant				
1	a	700/350	Irri. Scheduled at 80% of AW	-	56	-	-	-	-	-	E-30.7, B-86.0, GF-133.1, H -89	Lanzhou, China	SW (*T. aestivum*) cv. Ganmai 8139	CGC	Wu, *et al.*, 2004
	b		Irri. Scheduled at 40% of AW		27	-	-	-	-	-	E-8.8, B-8.4, GF-52.7, H-53.1				
2	a	350 600	N_{75} 40_{DAS}	-	40.2	29.7	-6.1	103.4	88.9	-	100.0	IARI, India	WW (*T. aestivum*) cv. HD-2285	OTC	Pal, *et al.*, 2005
	b		N_{150} 40_{DAS}	-	53.1	45	-14.7	117.5	90.0	-	113.4				
	c		N_{75} 60_{DAS}	-	35.9	44.8	12.0	126.5	131.6	-	127.5				
	d		N_{150} 60_{DAS}	-	49.8	38.4	59.6	143.9	147.6	-	144.9				
	e		N_{75} 90_{DAS}	-	14.3	22.8	-1.0	87.6	129.4	-	91.6				
	f		N_{150} 90_{DAS}	-	15.4	38	3.7	96.0	122.4	-	103.2				
3	a	375 550	Diploid	-	-	8.03	P 7.93	SC (-) 33.34	TC (-) 16.67	-	7.44	IARI, India	*WW (T. mono-coccum)* cv.PBW-373	FACE	Uprety *et al., 2009*
	b		Tetraploid	-	-	18.49	P 19.33	SC (-) 37.15	TC (-) 21.87	-	4.80	IARI, India	*WW T.durum* cv.PBW-373	FACE	Uprety *et al., 2009*
	c		Hexaploid	-	-	8.03	P 6.9	SC 7.23	1.71	-	7.44	IARI, India	*WW T.aesti-vum* cv.PBW-373	FACE	Uprety *et al., 2009*
4	a	350 900	Ele CO_2+ Vernalization	-	-	82.2	-	-	-	-	93.2	Canberra Australia	WW (*T.aesti-vum*) *cv* Hartog & *cv* Birch 75	GH	Masle, J. 2000
	b		Ele CO_2	-	-	80	-	-	-	-	91.1				
	c		Ele CO_2+ Vernalization	-	-	57.1	-	-	-	-	80.1				
	d		Ele CO_2	-	-	38	-	-	-	-	52.3				
5		375, +150	Ambient Elevated	-	-	-	-1.2	10.4	-	17.2	11.8	Stuttgart Germany	SW *(T. aestivum)* cv. Triso	Mini-FACE	Hogy *et al.*, 2009a
6		375, 526	Ambient Elevated	-	-	-	13.5	26.3	-	13.3	18.8	Stuttgart Germany	SW *(T.aestivum)* cv. Triso	Mini-FACE	Hogy, *et al.*, 2009b

Contd.

7		409 537	Ambient Elevated	-	-	-	-8.5	14.9	-	10.9	10.4	Stuttgart Germany	SW *(T.aestivum)* cv. Triso	Mini-FACE	Hogy, *et al.*, 2010
8		375, 526	Ambient Elevated	-	-	-	5.1	7.6		9.6	8.5	Stuttgart Germany	SW *(T.aestivum)* cv. Triso	Mini-FACE	Hogy, *et al.*, 2013
9	a	370 700 + 1°C	1991-92	-	-	-	-	-	-	-	↑ ns	Reading (UK)	WW *(T. aestivum)* cv. Hereward	Poly-ethylene chamber	Batts, *et al.*, 1998
	b	370 700 + 1.8ºC	1992-93	-	-	-	-	-	-	-	77.3				
	c	371 700 + 2 ºC	1993-94	-	-	-	-	-	-	-	68.5				
	d	372 700 + 1.2 ºC	1994-95	-	-	-	-	-	-	-	87.4				
10	a	352 712	Irrigated	-	0.9	-	-	-	-	-	6.45	Luan-cheng, China	WW *(T. aestivum)* cv. Kenong 9204	OTC	Qiao, *et al.*, 2010
	B	353 712	Drought	-	1.5	-	-	-	-	-	13.55				
11	a		CK (Control)	LAI-J	LAI-F	LAI-GF	-	-	-	-	-	Dingxi, China	SW (*T. aestivum)* cv. 'Dingxi 24	Under Field Situation	Li *et al.*, 2007
				0.00	0.00	0.00	-	-	-	-	-				
	b		C	2.37	7.89	10.94	-	-	-	-	-				
	c		W	1.18	35.08	25.52	-	-	-	-	-				
	d		WC	8.87	56.57	36.45	-	-	-	-	-				
	e		WN_1	15.38	42.54	42.70	-	-	-	-	-				
	f		WN_2	17.16	50.87	48.44	-	-	-	-	-				
	g		WN_1C	21.89	64.92	53.13	-	-	-	-	-				
	h		WN_2C	26.03	70.61	59.38	-	-	-	-	-				
12		370 700	-	-	-	32.14	-	-	-	-	36.4	Sendai Japan	WW*(T. aestivum)* cv. Hartog	GC	Seneweera *et al.*, 2005
13	a	350 600 at 40 DAS	CO_2 (600 ppm)	19.7	18.02	33.62	32.87	61.9	-	-	-	Varanasi India	WW (*T. aestivum)* cv. Malviya 234	OTC	Deepak & Agrawal, 1999
	b		SO_2 (0.06 ppm)	6	8.2	13.79	20.54	9.52	-	-	-				
	c		CO_2+SO_2 (600 + 0.06 ppm)	22.38	20.2	39.61	49.31	80.95	-	-	-				
	a	350 600 at 60 DAS	CO_2 (600 ppm)	14.7	13	38.15	36.55	65.85	-	18.7	-				
	b		SO_2 (0.06 ppm)	-10.03	-9.05	-14.84	-8.96	-9.75	-	6.25	-				
	c		CO_2+SO_2 (600 + 0.06 ppm)	17	16.1	29.47	30.34	85.36	-	12.5	-				

Contd.

14	a		A	-	0	0	0	0	-	-	-	Varanasi India	WW (*T. aestivum)* cv. HUW-37 and cv. K-9108	OTC	Mishra *et al.*, 2013
	b	388	B^1	-	↑	↑	↑	↑	-	-	-				
	c	548	C^1	-	↓	↓	↓	↓	-	-	-				
	d		D	-	↑	↑ns	↑ns	↑ns	-	-	-				
15	a	363	Irrigated	-	-	-	63	18	-	-	-	Maricopa USA	SW (*T. aestivum)* cv. Yecora Rojo	FACE	Wall *et al.*, 2006
	b	548	Drought	-	-	-	17	22	-	-	-				
16	a	380	High Vigour	-	-	-	0	-	0	-	0	Córdoba, Spain	SW (*T. aestivum)* cv.CV- 97, 207	GH	Gonzalez *et al*., 2013
	b	700	Low Vigour	-	-	-	97	-	67	-	43				
17	a	400	0 Kg N_2	-	8.10	3.12	-	-	-	-	-	Gansu, China	SW (*T. aestivum)*	OTC	Zhang *et al.*2013
	b	760	200 Kg N_2	-	1.98	2.35	-	-	-	-	-				
18	a		20 °C	-	-	-	13.33	-	TC 20.14	-	27.63	Ontart, Canada	WW(*T.aestivum)* cv Norstar	GC	Dahal *et al.*, 2013
	b	380	5 °C	-	-	-	6.94	-	TC -3.28	-	33.19				
	c	700	20 °C	-	-	-	11.11	-	TC 14.52	-	39.18		SW (*T. aestivum*) cv Katepwa		
	d		5 °C	-	-	-	16.67	-	TC -19.8	-	12.45				

Where, E=Elongation; B= Booting; GF= Grain filling; H= Harvest stages; P= Photosynthesis (μmol m^{-2} sec^{-1}); SC= Stomatal conductance (mol m^{-2} sec^{-1}); TC= Total chlorophyll (mg/g fresh wt); J= Jointing; F= Flowering; GF= Grain filling; A = Ambient CO_2 (388.4 ±37.3) and O_3 (48.4±4.6); B^1= CO_2 (548.2 ±53.7) and O_3 (48.4±4.6); C^1= CO_2 (388.4 ±37.3) and O_3 (55.2±5.3); D= CO_2 (548.2 ±53.7) and O3 (55.2±5.3); ↑= Significant increase as compare to control (o) at 40, 60 and 80 days after germination (DAG); ↓= Significant decrease as compare to control (o) at 40, 60 and 80 DAG, ns indicates non significant change; W= With 90 mm irrigation-three times but without applications of CO_2 forming fertilizer and CO_2 gas; WC= W+ artificial application of CO_2 gas (40 mmol mol^{-1}) but without CO_2 forming fertilizer application; WN_1= W+fertilizer application (NH4NO3: 250 kg hm^{-2}) but without CO_2 gas applications; WN_2= W+fertilizer application (NH4HCO3: 500 kg hm^{-2}) but without CO_2 gas applications; WN_1C= WC+WN_1; WN_2C= WC+WN_2; C = CO_2 40 mmol mol^{-1} but without irrigation and CO_2 forming fertilization; CK=Without irrigation, fertilization and CO_2 gas application; OTC= Open top Chamber; WW= Winter Wheat; SW=Spring Wheat, CGC= Closed growth chambers; OTC= Open top chambers; GH= Green house; GC= Growth Chambers; SW= Spring wheat; WW= Winter wheat.

biomass while four studies with six experimental findings in case of ear biomass (Hogy *et al.*, 2009a, Hogy *et al.*, 2009b, Hogy *et al.*, 2010 and Deepak & Agrawal, 1999) was suitable as per our objective. Whole plant biomass was studied by almost each and every researcher to review the impact on total dry matter production. Total 11 studies with 29 experimental findings were analyzed to review the impact on wheat varieties (table 1) the change in dry matter production (g/m^2) varies from 4.8 to 144.9 percent over control. Plant dry weight on different growth stages i.e. Elongation (E), booting (B), grain filling (GF), and harvest stages (H) under two water regimes with elevated CO_2 levels was studied (Wu, *et al.*, 2004). Highest change was observed at GF under 80% FWC while at 40% FWC maximum impact was observed at harvest stages. Impact of elevated CO_2 on physiological aspects like Photosynthesis-P (µmol m^{-2} sec^{-1}), Stomatal conductance-SC (mol m^{-2} sec^{-1}), and Total chlorophyll-TC (mg/g fresh weight) of diploid, tetraploid and hexaploid wheat species was also considered in this review study. The result shows that the Tetraploid species is quiet efficient in P, SC and TC as compared to diploid, and hexaploid under elevated CO_2. TC was also observed under various temperatures and CO_2 levels (Dahal *et al.,* 2013) result shows that under ambient CO_2 condition when temperature increase upto 20°C wheat has quite positive response but when temperature decrease up to 5°C negative response for TC was observed under similar CO_2 condition. Under elevated CO_2 condition at 20°C temperature TC value resulted quite well but when temperature decreases up to 5°C the TC reduces drastically. This negative impact is attributed to chilling injury under low temperature.

Effect of elevated CO_2 on yield and yield components

Number of factors associated with the yield i.e. total number of plant per unit ground area, total number of fertile tiller or panicle per plant, total number of grain per ear and grain weight or test weight. More or less these yield components got affected by the elevated level of CO2. The most important factor that has ability to influence the yield with greater extent due to elevated CO2 is number of fertile tiller or ear bearing tillers per unit area. This in itself increases the grain number per unit area which will contribute to total yield. The grain number per ear was constantly affected due to elevated level of CO_2 because of little change in environmental condition may affect the grain filling. The effect of elevated on individual grain mass was more variable, and generally smaller, than effects on ears per meter square.

Total 11 peer reviewed study with 54 experiments with total 131 dataset used in Meta analysis (Table 2). Major emphasis was given for seed yield, Biomass yield and some yield parameters like- number of ear/plant, grain number/ear, grain number/m_2, total grain weight (TGW) and Harvest Index (HI). Percent change from control to elevated CO_2 was calculated using the formula (Eq. 1).

In case of grain yield almost all the studies have reported positive change under elevated CO_2 or in combination with other factors like nitrogen levels, moisture regimes, drought etc. negative interaction was observed when CO_2 is applied in combination with SO_2 (Deepak & Agrawal, 1999) both yield and yield component of wheat crop. Biomass yield was analyzed using five studies with 10 experiments at three locations i.e. United Kingdom (Batts *et al.,* 1997), India (Uprety *et al.*, 2009) and Germany (Högy *et al.*, 2009a, Högy *et al.*, 2009b, and Hogy *et al.,* 2010a). Response of elevated CO_2 for biomass yield varies from 10.4-31 percent. Number ear /plant have very good response under elevated CO_2 condition the response varies between 0.2 (Xiao, *et al.*, 2009) to 72 percent (Li, *et al.,* 2007). Grain number per ear is the most important factor that decided the total yield per unit area or per plant. Comprehensive study has been done to evaluate the status of grain number per ear and grain number per m2. Grain number per on the basis of per plant or ear is quite effective as compared to area basis because spacing of crop varies variety to variety. Remarkable change in grain number was observed under elevated CO_2 with ample supply of water and nutrients. Under drought situation grain number per ear shows negative response even under elevated CO_2 this might be due to increase in canopy temperature at the time of grain filling (Qiao, *et al.*, 2010). TGW shows negative response under elevated CO_2 in most of the study not only under FACE but even under OTC (Qiao, *et al.*, 2010) and under open field situation (Li *et al.*, 2007) in absence of further additives. Continuous three studies under mini –FACE by Högy *et al.*, in year 2009a, 2009b and in 2010 but in year 2013 same variety shows positive response in term of TGW.

Table 2: Impact of elevated CO_2 on yield and yield component of wheat crop

S. No.	*CO_2 level (ppm)*	*Interaction with other factor*	*Seed Yield (%)*	*Biomass yield (%)*	*Percent Change in Yield Parameters*					*Study area*	*Cultivars*	*Tech. used*	*Source*
					No. of Ear/ plant	*Grain No/ear*	*Grain No. M^{-2}*	*TGW*	*HI*				
1a	370; 700 +1ºC	1991-92	7-44↑	6-31↑	-	82.5	-	-	-	Reading (UK)	W.W (*T. aestivum*) cv. Hereward	Polyethylene chamber	Batts *et al.*, 1997
b	370; 700 + 1.8ºC	1992-93	7 2 - 168↑	34↑	-	71.5	82.8	-	-				Batts *et al.*, 1997
c	370 700 + 2ºC	1993-94	46-7↓	8-17↑	-	46.4	78.4	-	-				Batts *et al.*, 1997
d	300 700+1.2ºC	1994-95	58-31↓	33-17↓	-	15.8	-	-	-				Batts *et al.*, 1997
2a	350600	At 60 DAS CO_2 (600)	30.45	-	35.13	1.22	35.71	3.86	16.22	Varanasi India	W.W (*T. aestivum*) cv. Malviya 234	OTC	Deepak & Agrawal, 1999
b	350; 600	SO_2 (0.06) ppm	-15.34	-	-27.02	1.84	-19	4.45	-4.67				Deepak & Agrawal 1999
c	350; 600	CO_2+SO_2 (600+0.06) ppm)	41.8	-	56.75	2.45	40.28	0.99	18.71				Deepak & Agrawal 1999
3a	-	CK (Control)	0	-	0	0	-	0	0	Dingxi China	SW (*T. aestivum*) cv. 'Dingxi 24	Under Field Situation	Li *et al.*, 2007
b	-	C	4.2	-	4	1.5	-	-0.3	0.2				Li *et al.*, 2007
c	-	W	73.4	-	47.3	7.5	-	-0.6	-0.6				Li *et al.*, 2007
d	-	WC	90.4	-	49.5	13.4	-	1.1	0.9				Li *et al.*, 2007
e	-	WN_1	148	-	51.9	35.8	-	3	4.7				Li *et al.*, 2007
f	-	WN_2	163.6	-	63.4	62.7	-	3.3	3.9				Li *et al.*, 2007
g	-	WN_1C	180.5	-	66.7	97	-	5.2	5.6				Li *et al.*, 2007
h		WN_2C	197.1	-	72.3	100	-	5.8	6.7				Li *et al.*, 2007
4a	375; 700	Diploid	13.25	21.37	-	-	-	5.33	5.41	IARI, India	*T. monococcum* cv.PBW-373	FACE	Uprety *et al.*, 2009
b		Tetraploid	15.9	25.9	-	-	-	-10.04	10.58		*T. durum* cv.PBW-373	FACE	Uprety *et al.*, 2009
c		Hexaploid	13.25	21.37	-	-	-	5.33	5.41		*T. aestivum* cv.PBW-373	FACE	Uprety *et al.*, 2009

5a	350; 700	80% of field water capacity	166	-	-	140	-	-	30	Lanzhou, China	SW (*T. aestivum*) cv. Ganmai 8139	CGC	Wu, *et al.*, 2004
b	350; 700	40% of field water capacity	78	-	-	42	-	-	41.9				Wu, *et al.*, 2004
6a	380; 410	CO_2	5.1		0.1	2.5		12.5	1.3	Guyuan, China	SW (*T. aestivum*) cv. AD-2)	OTC	Xiao, *et al.*, 2009
b	380; 410	CO_2+NH_4 CO_3	82		-0.2	15.6		51.7	11.9				Xiao, *et al.*, 2009
7	375; 150	Ambient Elevated	23.08	11.8	6.9	7.22	12.2	-1.7	-	Stuttgart, Germany	SW (*T. aestivum*) cv. TRISO	Mini-FACE	Högy *et al.*, 2009a
8	375; 526	Ambient Elevated	13.5	18.8	22.4	-4.9	14.8	-1.9	-5.3	Stuttgart, Germany	SW (*T. aestivum*) cv. TRISO	FACE	Högy *et al.*, 2009b
9	409; 537	Ambient Elevated	10.7	10.4	↔	12.2	12	-0.3	0.5	Stuttgart, Germany	SW (*T. aestivum*) cv. TRISO	Mini- FACE	Hogy *et al.*, 2010
10	Ambient; +150	Ambient Elevated	10.8	-	4.7	0.5	5.2	5.4	2.2	Stuttgart, Germany	SW (*T. aestivum*) cv. TRISO	Mini-FACE	Högy *et al.*, 2013
11a	352; 712	Irrigated	6.5	-	8.7	8.6	-	-2.42	-	Luancheng, China	WW (*T. aestivum*) cv. Kenong 9204	OTC	Qiao, *et al.*, 2010
b	353; 712	Drought	10.43	-	17.11	-2.8	-	-1.39	-				Qiao, *et al.*, 2010

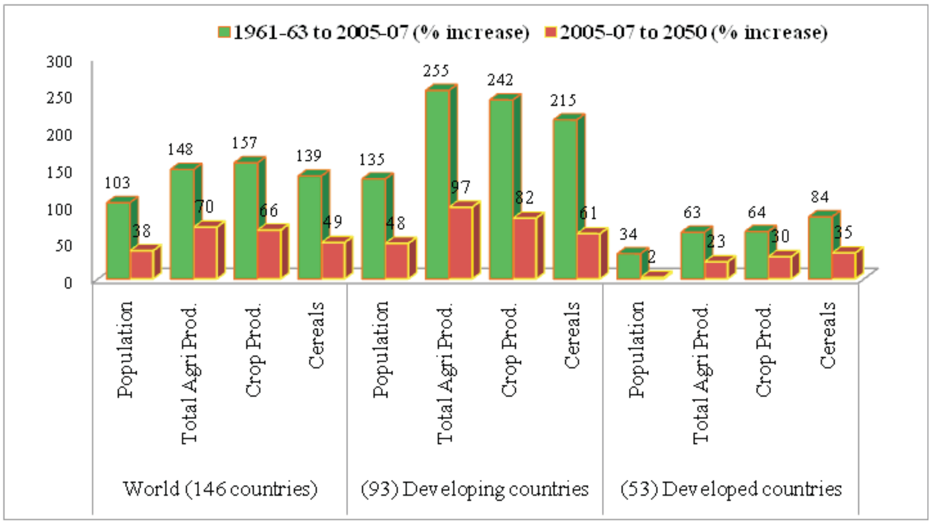

Fig. 1a. past (1961) present (2005) and future (2050) scenario of population and total agriculture production, Crop production (all crops excluding cereals), Cereals production.

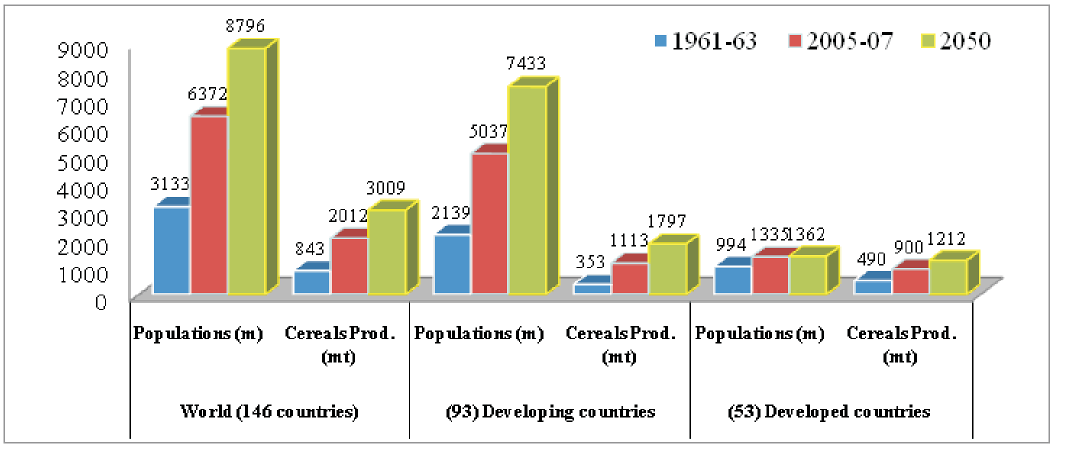

Fig.1b. past (1961) present (2005) and future (2050) scenario of population and Cereal production.

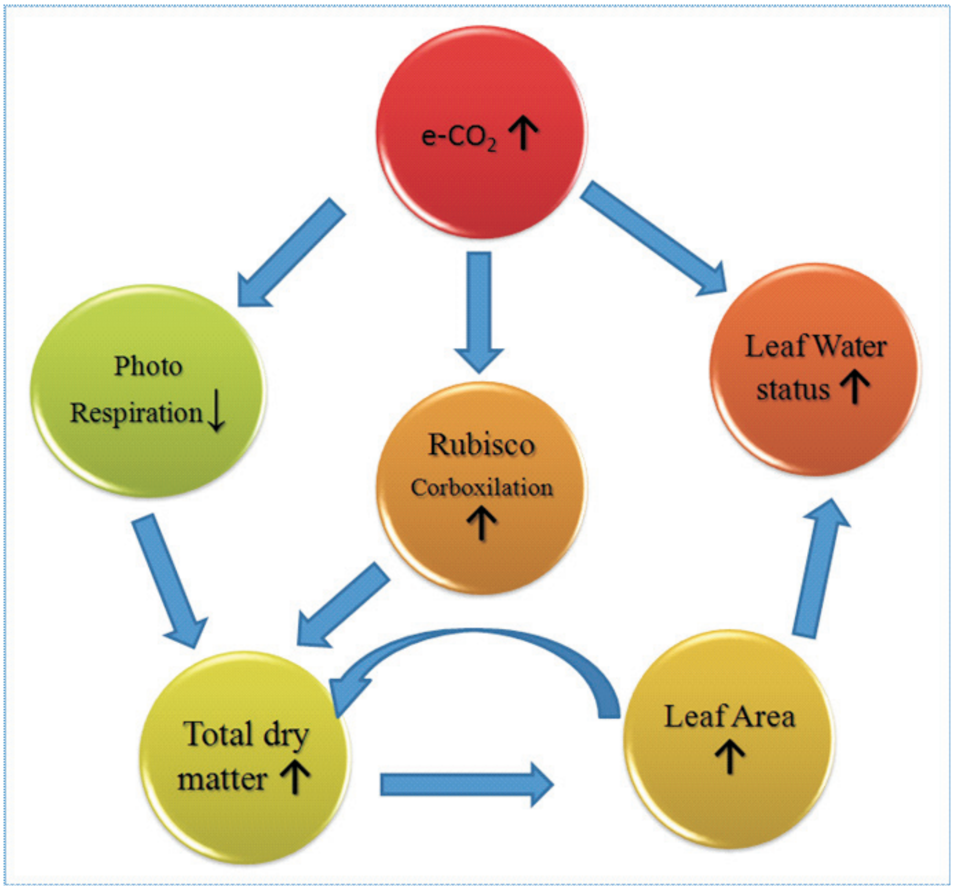

Fig. 2. Impact of elevated CO2 on Wheat crop

Conclusion

Climate change affects almost every assets of life, agriculture will not ruling out. Critical review of results from 20 studies with more than 50 research experiment from 9 countries was reviewed. Study focused on various aspects like water, temperature and nutrients simultaneously elevated CO_2 was studied. Major emphasis was given to elaborate the need of such kind of studies, especially in the context of burgeoning world population and decreasing land area per capita. These two aspects would be major challenges to meet the future food requirement. CO_2 have a positive response on growth and yield of wheat crop. Each unit increase in CO_2 total biomass will increase linearly. Climate change not only govern with elevated CO_2 it also included the higher level of temperature and accumulation of harmful gases like SO_2, CO etc. When temperature combines with CO_2 the response will become lesser or in other word negative response of temperature was compensated by elevated level of CO_2. Primarily CO_2 is used as a food material by plant but when it mixed up with other gases it gives negative response both in term of growth and yield (Barnes, *et al.*, 1995). Although elevated CO_2 have positive response under drought condition by increasing water use efficiency but the elevated level of temperature leads to drought in various parts of world especially in African countries. That situation will nullify our food security. If we consider the report of IPCC combination of two basic factors of climate change i.e. doubled CO_2 and 2-4°C increase in temperature will have negative response for food productivity (Deryng *et al.*, 2014). Beside the environmental factors several others related with soil physical, chemical and biological factors may also influence the productivity of wheat in changing climate. Thus the basic factors related with crop production like soil, ecology, and hydrology needs to study in comparison with elevated CO_2 and temperature, though significant uncertainty about net effects of rising CO_2 on wheat yield may be expected.

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